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(54) Title: MULTI-PHASE STEEL SHEET EXCELLENT IN HOLE EXPANDABILITY AND METHOD OF PRODUCING THE SAME
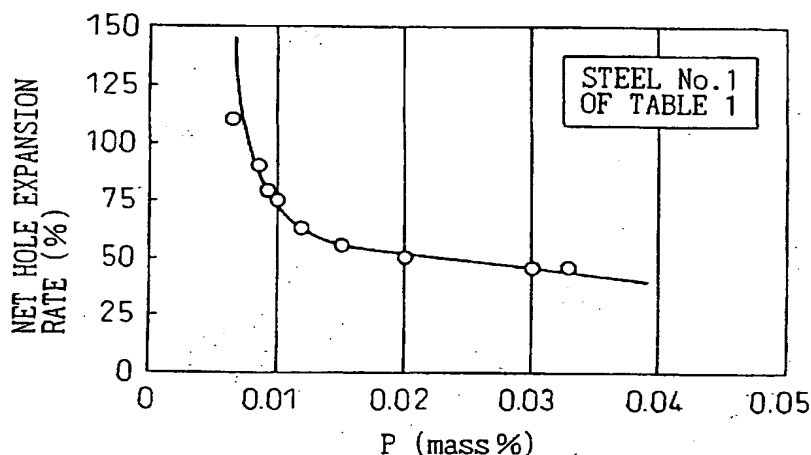
(57) Abstract: The present invention provides a steel sheet excellent in both a balance between strength and elongation and a balance between strength and hole expandability, in other words, a multi-phase steel sheet having an excellent balance between strength and hole expandability. The present invention is a multi-phase steel sheet excellent in hole expandability characterized in that: the steel sheet contains, as chemical components in mass, C: 0.03 to 0.15%, P: not more than 0.010%, S: not more than 0.003%, and either one or both of Si and Al in a total amount of 0.5 to 4%, and one or more of Mn, Ni, Cr, Mo and Cu in a total amount of 0.5 to 4%, with the balance consisting of Fe and unavoidable impurities; the microstructure at a section of the steel sheet is composed of either one or both of retained austenite and martensite which account(s) for 3 to 30% in total in area percentage and the balance consisting of either one or both of ferrite and bainite; the maximum length of the crystal grains in the microstructure is not more than 10 microns; and the number of inclusions 20 microns or larger in size at a section of the steel sheet is not more than 0.3 piece per square millimeter.

DESCRIPTION

MULTI-PHASE STEEL SHEET EXCELLENT IN HOLE EXPANDABILITY AND METHOD OF PRODUCING THE SAME

Technical Field

The present invention relates to a multi-phase steel sheet excellent in hole expandability, aiming at the application for automobiles, such as passenger cars and trucks, etc., for industrial machines, or the like, and a method of producing the same.

Background Art

In recent years, demands for high strength steel sheets have been growing with the increasing needs mainly for the weight reduction of automobile bodies and the assurance of the safety of passengers in a collision. In particular, the application of steels of TS 590 MPa class (60 kgf/mm² class) in tensile strength has rapidly expanded.

As a steel sheet used for such application, a multi-phase steel sheet comprising retained austenite and/or martensite is widely known. For example, as Japanese Unexamined Patent Publication No. H9-104947 discloses, a steel sheet having an excellent balance between strength and elongation (a total elongation is 33.8 to 40.5% when a tensile strength is 60 to 69 kgf/mm²) is obtained by containing retained austenite in an appropriate quantity therein. In this technology, however, a technology regarding the balance between strength and hole expandability has not been sufficiently considered and, in particular, technological requirements for ultra-low P, the control of the maximum length of a microstructure and inclusions and the control of the hardness of a microstructure are not, in the least, taken into consideration. Therefore, the properties of the steel sheet have been inferior (a hole expansion ratio d/d0 is

1.46 to 1.68, namely 46 to 68% in terms of a net hole
expansion rate, when a tensile strength is 60 to 69
kgf/mm^2) and the application has been limited.

In the meantime, Japanese Unexamined Patent

5   Publication No. H3-180426 discloses a bainite sheet steel
excellent in the balance between strength and hole
expandability (a hole expansion ratio d/d0 is 1.72 to
2.02, namely 72 to 102% in terms of a net hole expansion
rate, when a tensile strength is 60 to 67 kgf/mm^2).

10   However, since this technology provides not a multi-phase
structure but the equalization of a structure (a bainite
single phase structure), as a means of improving the net
hole expansion rate, the balance between strength and
elongation is rather insufficient (a total elongation is

15   27 to 30% when a tensile strength is 60 to 67 kgf/mm^2)
and the application is again limited.

That is, though, in the press forming of auto parts,
punch stretch formability represented by the balance
between strength and elongation and stretch flange

20   formability represented by the balance between strength
and hole expandability are two major components of
forming, such a technology, satisfying both the
components simultaneously, has not been available and the
excellence in both has been the key to the expansion of

25   the application.

In recent years while the shift to high strength
steel sheets is progressing at an increasing rate due to
global environmental issues, as their application to
components with high degree of forming difficulty has

30   been taken into consideration, a steel sheet excellent in
both the balance between strength and elongation and the
balance between strength and hole expandability, in other
words, a multi-phase steel sheet excellent in the balance
between strength and hole expandability, has been

35   demanded.

Disclosure of the Invention

The object of the present invention is, by solving the problems of the conventional steel sheets, to provide a steel sheet having both the excellent balance between strength and hole expandability (not less than 35,000 MPa%, preferably not less than 46,000 MPa%, in terms of the value obtained by multiplying a tensile strength by a net hole expansion rate) and the excellent balance between strength and elongation (not less than 18,500 MPa%, preferably not less than 20,000 MPa%, in terms of the value obtained by multiplying a tensile strength by a total elongation), that is, a multi-phase steel sheet excellent in hole expandability, and a method of producing the same.

Both of the balance between strength and hole expandability (MPa·%), and the balance between strength and elongation (MPa·%) are indexes of press-formability. If these values are large, the resultant products exhibit excellent properties. The balance between strength and hole expandability is represented by the product of the value of strength (MPa) obtained by tensile test and the value of hole expansion ratio (%) obtained by hole expansion test. Further, the balance between strength and elongation is represented by the product of the value strength (MPa) obtained by tensile test and the value of total elongation obtained by tensile test. In the steel sheet which is generally used, if tensile strength increases, both of hole expansion ratio and elongation decrease and, as a result, both of the balance between strength and hole expandability (MPa·%), and the balance between strength and elongation (MPa·%) exhibit low values. On the other hand, according to the present invention, lowering the value both of hole expansion ratio and elongation can be restrained and it is possible to obtain the high values of the balance between strength and hole expandability (MPa·%), and the balance between strength and elongation (MPa·%).

The present inventors have earnestly studied, from

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the viewpoint of integrated manufacturing from
steelmaking to hot rolling, and have finally invented a
multi-phase steel sheet excellent in hole expandability
and a method of producing the same.

5   The gist of the present inventions is as follows:

(1) A multi-phase steel sheet excellent in hole
expandability characterized in that:

the steel sheet contains, as chemical components in
mass,

10   C: 0.03 to 0.15%,

P: not more than 0.010%,

S: not more than 0.003%, and
either one or both of Si and Al in a total amount of 0.5
to 4%, and one or more of Mn, Ni, Cr, Mo and Cu in a

15   total amount of 0.5 to 4%, with the balance consisting of
Fe and unavoidable impurities;

the microstructure at a section of the steel sheet
is composed of either one or both of retained austenite
and martensite which account(s) for 3 to 30% in total in

20   area percentage and the balance consisting of either one
or both of ferrite and bainite;

the maximum length of the crystal grains in the
microstructure is not more than 10 microns; and

the number of inclusions 20 microns or larger in

25   size at a section of the steel sheet is not more than 0.3
pieces per square millimeter.

(2) A multi-phase steel sheet excellent in hole
expandability characterized in that:

30   the steel sheet contains, as chemical components in
mass,

C: 0.03 to 0.15%,

P: not more than 0.010%,

S: not more than 0.003%, and

35   either one or both of Si and Al in a total amount of 0.5
to 4%, and one or more of Mn, Ni, Cr, Mo and Cu in a
total amount of 0.5 to 4%, with the balance consisting of

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Fe and unavoidable impurities;

the microstructure at a section of the steel sheet
is composed of either one or both of retained austenite
and martensite which account(s) for 3 to 30% in total in
area percentage, pearlite which accounts for more than 0%
to not more than 3% in area percentage, and the balance
consisting of either one or both of ferrite and bainite;

the maximum length of the crystal grains in the
microstructure is not more than 10 microns; and

the number of inclusions 20 microns or larger in
size at a section of the steel sheet is not more than 0.3
pieces per square millimeter.

(3) A multi-phase steel sheet excellent in hole
expandability according to the item (1) or (2),
characterized in that the micro Vickers hardness of
bainite is less than 240.

(4) A multi-phase steel sheet excellent in hole
expandability according to any one of the items (1) to
(3), characterized by further containing, as chemical
components in mass, one or more of Nb, V and Ti in a
total amount of 0.3% or less.

(5) A multi-phase steel sheet excellent in hole
expandability according to any one of the items (1) to
(4), characterized by further containing, as a chemical
component in mass, B of 0.01% or less.

(6) A multi-phase steel sheet excellent in hole
expandability according to any one of the items (1) to
(5), characterized by further containing, as chemical
components in mass, either one or both of Ca of 0.01% or
less and REM of 0.05% or less.

(7) A method of producing a multi-phase steel sheet
excellent in hole expandability, which steel sheet

contains, as chemical components in mass,

C: 0.03 to 0.15%,

P: not more than 0.010%,

S: not more than 0.003%, and

either one or both of Si and Al in a total amount of 0.5 to 4%, and one or more of Mn, Ni, Cr, Mo and Cu in a total amount of 0.5 to 4%, with the balance consisting of Fe and unavoidable impurities, characterized by:

when molten steel with said components is refined, circulating the molten steel not less than 1.5 times after flux for desulfurization is added at the time of the desulfurization of the molten steel;

further, when a steel sheet is produced by hot-rolling a slab obtained by casting said molten steel, conducting the finish rolling by controlling the finish-rolling entry temperature to 950°C or higher and the finish-rolling exit temperature within the range from 780 to 920°C; and

coiling the steel sheet thus obtained at a temperature of 500°C or lower.

(8) A method of producing a multi-phase steel sheet excellent in hole expandability according to the item (7), characterized in that the steel sheet further contains, as chemical components in mass, one or more of Nb, V and Ti in a total amount of 0.3% or less.

(9) A method of producing a multi-phase steel sheet excellent in hole expandability according to the item (7) or (8), characterized in that the steel sheet further contains, as a chemical component in mass, B of 0.01% or less.

(10) A method of producing a multi-phase steel sheet excellent in hole expandability according to any one of the items (7) to (9), characterized in that the steel sheet further contains, as chemical components in mass,

either one or both of Ca of 0.01% or less and REM of
0.05% or less.

[Brief Description of the Drawings]

5   Fig. 1 is a graph showing the effect of the chemical
component P on a net hole expansion rate.
          Fig. 2 is a graph showing the effect of the maximum
length of a microstructure on a net hole expansion rate.
          Fig. 3 is a graph showing the effect of the number

10   of inclusions on a net hole expansion rate.
          Fig. 4 is a schematic drawing showing the refining
of molten steel when an RH is used.
          Fig. 5 is a graph showing the effect of the
frequency of the reflux of molten steel after flux

15   addition for desulfurization on the number of inclusions.
          Fig. 6 is a graph showing the effect of finish-
rolling entry and exit temperatures at the finishing mill
in hot rolling on the maximum length of a microstructure.

20   [Best Mode for Carrying Out the Invention]
          The present invention is explained in detail
hereunder.
          First, the chemical components are explained.
          C is an important element for stabilizing austenite

25   and obtaining a multi-phase structure, and C is added at
not less than 0.03 mass % in order to stabilize austenite
and to obtain either one or both of retained austenite
and martensite in the total amount of not less than 3% in
area percentage. However, the upper limit of C content

30   is set at not more than 0.15 mass %, preferably not more
than 0.11 mass %, in order to avoid the deterioration of
weldability and an adverse influence on a net hole
expansion rate.
          P is a key element among the addition elements of

35   the present invention. The effect of P is demonstrated
in Fig. 1. Figure 1 shows the result of the
investigation on the relationship between the P content

and the net hole expansion rate of a steel sheet, using
the steel sheets having the chemical components of Steel
No. 1 in Table 1.

[Table 1]

Steel No.	Chemical components (mass %)							
	C	Si	Mn	P	S	Al	N	Al+Si
1	0.11	1.88	1.40	0.006-0.034	0.001	0.03	0.003	1.41
2	0.10	1.40	1.40	0.008	0.001	0.04	0.002	1.44

A net hole expansion rate is calculated based on the
Japan Iron and Steel Federation Standard JFS T 1001-1996.
From Fig. 1, the net hole expansion rate improves
remarkably and exponentially by controlling the P content
to not more than 0.010 mass % and its effect on the net
hole expansion rate, which has not yet been assumed
within the range of conventional concepts, is recognized.
By so doing, press cracking can be avoided. Although the
reason is not completely clear, it is supposed that the
reduction of P content improves the properties of the
edge of a punched hole (for instance: the minimization of
facet size, the reduction of roughness and the reduction
of microcracks on a fractured plane; the suppression of
the deterioration of workability in a microstructure on a
sheared plane; and the like), and leads to the
improvement of a net hole expansion rate.

S content is set at not more than 0.003 mass %,
preferably not more than 0.001 mass %, from the viewpoint
of preventing the deterioration of a net hole expansion
rate and weldability caused by sulfide-system inclusions.

Si and Al are elements useful for obtaining a multi-
phase structure. They make either one or both of
retained austenite and martensite account for not less
than 3% in total in area percentage and have the function
of improving a net hole expansion rate, by promoting the
formation of ferrite and suppressing the formation of
carbide, and further by strengthening ferrite, thus
reducing the hardness difference between ferrite and hard
phases (such as bainite and martensite) and contributing

to the uniformity of a structure. Moreover, they act
also as deoxidizing elements. From the above-mentioned
viewpoint, the lower limit of the total addition amount
of either one or both of Si and Al should be not less
than 0.5 mass %. Considering the balance between the
cost and the effect, the upper limit of the total
addition amount is set at not more than 4 mass %.

With regard to the addition amount of each of Si and
Al, the following may be taken into consideration.

When excellent surface quality is required in
particular, either one of the means of avoiding Si scale
by controlling the Si content to less than 0.1 mass %,
preferably not more than 0.01 mass %, and the means of
making Si scale harmless (making scale less conspicuous
by forming the scale all over the surface) by controlling
the Si content rather to more than 1.0 mass %, preferably
more than 1.2 mass %, may be adopted.

It is also possible to increase the addition amount
of Al and reduce the addition amount of Si to meet the
requirement of material properties, for example, in a
case where it is desired to lower a tensile strength by
making use of the difference between Si and Al in the
function of strengthening ferrite.

Al may be limited to not more than 0.2 mass %,
preferably not more than 0.1 mass %, considering the
drawbacks in steelmaking, such as the erosion of
refractory materials, nozzle clogging and the like, and
the material properties.

Mn, Ni, Cr, Mo, and Cu are elements useful for
obtaining a multi-phase structure, and also are elements
which strengthen ferrite. From the above-mentioned
viewpoint, the lower limit of the total addition amount
of one or more of them should be not less than 0.5 mass
%. However, considering the balance between the cost and
the effect, the upper limit of the total addition amount
is set at not more than 4 mass %.

Furthermore, one or more of Nb, V, Ti, B, Ca and REM

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may be added as selective elements.

Nb, V and Ti are elements effective for a higher
strength. However, considering the balance between the
cost and the effect, the total addition amount of one or
more of those elements is set at not more than 0.3 mass
%.

B has a function as a strengthening element, and may
be added by not more than 0.01 mass %. In addition, B
also has the effect of mitigating the adverse effect of
P.

Ca may be added by not more than 0.01 mass % since
Ca further improves a net hole expansion rate by
controlling the shape of sulfide-system inclusions
(spheroidizing).

Moreover, REM may also be added by not more than
0.05 mass % for the same reason.

In addition, N may be added by not more than 0.02
mass %, if required, aiming at the stabilization of
austenite and the strengthening of a steel sheet.

Next, a microstructure is explained hereunder.

In order to obtain an excellent net hole expansion
rate, from the viewpoint of not deteriorating the
uniformity of a fractured surface size, one of the
properties of the edge of a punched hole, and the like,
which uniformity has been improved by the ultimate
reduction of P, the control of the maximum length of
crystal grains in a microstructure and the control of the
amount and size of inclusions are especially important.
Therefore, that is explained first.

As the crystal grain size of a microstructure
affects the fractured surface size at the edge of a
punched hole, it affects a net hole expansion rate
remarkably. Even in the case where the average size of
crystal grains in a microstructure is fine, if the
maximum grain size is large, it adversely affects a net
hole expansion rate. As a microstructure is composed of
many crystal grains, a net hole expansion rate cannot be

governed by the average grain size: when a big crystal
grain exists among many crystal grains, it adversely
affects the net hole expansion rate even if the average
grain size is fine. Here, with regard to the size of a
5   crystal grain, not a circle-reduced diameter but the
maximum length thereof affects a net hole expansion rate.
Fig. 2 shows the result of the investigation on the
relationship between the maximum length of a
microstructure in a steel sheet and the net hole
10   expansion rate of the steel sheet, using the steel sheets
having the chemical components of Steel No. 2 in Table 1.
As shown in Fig. 2, the net hole expansion rate improves
remarkably and exponentially when the maximum length of a
microstructure is not larger than 10 microns, and its
15   effect on the net hole expansion rate, which has not yet
been assumed within the range of the conventional
concept, is recognized. By so doing, press cracking can
be avoided.
Here, the maximum length of a microstructure was
20   calculated from an optical micrograph under the
magnification of 400 taken at a section perpendicular to
the rolling direction of a steel sheet after the section
was etched with a nitral reagent and the reagent
disclosed in Japanese Unexamined Patent Publication No.
25   S59-219473, averaging all over the section along the
thickness direction.
Moreover, with regard to inclusion control, a net
hole expansion rate can be improved by reducing the
number of coarse inclusions. The number of coarse
30   inclusions was obtained by observing a polish-finished
section along the rolling direction of a steel sheet with
a microscope (400 magnifications) and integrating the
number of coarse inclusions 20 microns or larger in
maximum length. Fig. 3 shows the result of the
35   investigation on the relationship between the number of
coarse inclusions (20 microns or larger in maximum
length) in a steel sheet and the net hole expansion rate,

using the steel sheets having the chemical components of
Steel No. 2 in Table 1. It is understood that, when the
number of coarse inclusions (20 microns or larger in
maximum length) is not more than a specified number (not

5　　more than 0.3 piece per square millimeter), the net hole
expansion rate can be improved remarkably and press
cracking can be avoided.

In addition, controlling the micro Vickers hardness
of bainite to less than 240 acts preferably on the

10　　improvement of hole expandability. The reduction of the
hardness of bainite lowers the hardness difference
between ferrite and bainite and thus contributes to the
improvement of the uniformity of a structure. However,
if the micro Vickers hardness of bainite exceeds 240, the

15　　hardness difference between ferrite and bainite deviates
from the range desirable for hole expandability and
further the deterioration of hole expandability is caused
by the deterioration of workability of the bainite
itself. The reduction of P (not more than 0.01%) largely

20　　contributes to enhancing the effect, but details are not
known.

Here, the micro Vickers hardness of bainite is
obtained by identifying bainite by etching a section
perpendicular to the rolling direction of a steel sheet

25　　with the reagent disclosed in Japanese Unexamined Patent
Publication No. S59-219473, and by averaging the values
measured at five points (averaging the values excluding
the maximum and minimum values from among the values
measured at seven points) under a load of 1 to 10 gr.

30　　Furthermore, in order to obtain an excellent balance
between strength and elongation as well as an excellent
balance between strength and hole expandability, it is
essential to control the kind and the area percentage of
a multi-phase structure.

35　　An excellent balance between strength and elongation
(not less than 18,500 MPa% in terms of the value obtained
by multiplying a tensile strength by a total elongation)

and an excellent balance between strength and hole expandability (not less than 35,000 MPa% in terms of the value obtained by multiplying a tensile strength by a net hole expansion rate) are obtained by controlling the

5   total area percentage of either one or both of retained austenite and martensite to 3 to 30%.

When the total area percentage of either one or both of retained austenite and martensite is less than 3%, it becomes impossible to obtain the stable effect of

10   improving the balance between strength and elongation, which is to be obtained by the retained austenite and martensite. Therefore, its lower limit is set at 3%.

When the total area percentage of either one or both of retained austenite and martensite is more than 30%,

15   the effect of improving the balance between strength and elongation is saturated and the deterioration of a net hole expansion rate and the like are caused. Therefore, from the viewpoint of press formability, the upper limit of the total area percentage is set at 30%.

20   Here, it is preferable that pearlite is not contained in a steel sheet since it hinders a balance between strength and elongation and a balance between strength and hole expandability. Therefore, the area percentage of pearlite is determined to be not more than

25   3% at most, preferably not more than 1%.

It is more desirable to add the following restrictions in addition to the above restrictions.

When a particularly excellent balance between strength and elongation (not less than 20,000 MPa%) is

30   required, it is desirable that the area percentage of retained austenite is set at not less than 3%.

Moreover, when a particularly excellent balance between strength and hole expandability (not less than 46,000 MPa% in terms of the value obtained by multiplying

35   a tensile strength by a net hole expansion rate) is required, it is desirable that the area percentage of martensite is set at not more than 3%.

On the other hand, when a low yield ratio (not more than 70% in terms of yield ratio YR which is a value obtained by dividing a yield stress by a tensile strength and then multiplying the divided value by 100) is required from the viewpoint of the shape fixability, the area percentage of martensite is set at not less than 3%.

Preferably, by controlling the maximum length of the microstructure of retained austenite and/or martensite to not more than 2 microns, the effect increases yet further.

The remainder structure of a microstructure consists of either one or both of ferrite and bainite, and by controlling the total area percentage of ferrite and bainite to not less than 80%, the deterioration of press formability, which is caused by hard structures other than ferrite and bainite combining with each other in the form of a network, can be suppressed.

Due to the effect described above, both an excellent balance between strength and hole expandability (not less than 35,000 MPa%, preferably not less than 46,000 MPa%, in terms of the value obtained by multiplying a tensile strength by a net hole expansion rate) and an excellent balance between strength and elongation (not less than 18,500 MPa%, preferably not less than 20,000 MPa%, in terms of the value obtained by multiplying a tensile strength by a total elongation) can be obtained simultaneously, and press formability improves markedly.

Here, the identification of the constitution of a microstructure, the measurement of an area percentage, and the measurement of the maximum length of retained austenite and/or martensite were carried out with an optical micrograph under the magnification of 1,000 taken at a section perpendicular to the rolling direction of a steel sheet after the section was etched with a nitral reagent and the reagent disclosed in Japanese Unexamined Patent Publication No. S59-219473, and by X-ray analysis.

Next, the production method is explained hereunder.

Firstly, when molten steel is refined in a steelmaking process, it is important to let the molten steel reflux not less than 1.5 times after the addition of flux for desulfurization at the time when the molten steel is desulfurized using a secondary refining apparatus such as an RH. Here, the reflux of molten steel is represented by the amount of molten steel that circulates the inside of a secondary refining apparatus, such as an RH, per unit time, and there are various formulas for the computation. For example, as disclosed in "The Refining Limitation of Impurity Elements in a Mass Production Scale" (Iron and Steel Institute of Japan, the Forum of Elevated Temperature Refining Process Section, and Japan Society for the Promotion of Science, the 19th Steelmaking Committee, Reaction Process Workshop, March 1996, P. 184-187), the amount of refluxed molten steel Q expressed by the following Equation 1 is defined as the refluxed amount of one time:

Refluxed amount $Q = 11.4 \times V^{1/3} \times D^{4/3} \times \{\ln(P1/P0)\}^{1/3} \times k$ .... Eq 1,

where

Q: Amount of refluxed molten steel (t/min.),

V: Flow rate of refluxed gas (Nl/min.),

D: Inner diameter of snorkel (m),

P0: Pressure in vacuum chamber (Pa),

P1: Pressure at injection port of refluxed gas (Pa), and

k: Constant (a constant determined based on secondary refinement apparatus, 4 in this case).

The schematic drawing of the refining of molten steel using an RH is shown in Fig. 4. Two snorkels 3 of the degassing chamber 2 are dipped into the molten steel ladle 1, gas is blown from underneath one of these snorkels (in this case, Ar is blown from underneath one of the snorkels through the injection lance 4), then, the molten steel in the molten steel ladle 1 rises and enters the degassing chamber 2, and after the degassing process, the molten steel descends and returns from the other

snorkel 3 to the molten-steel ladle. Here, though the example wherein a secondary refining apparatus employing an RH is used is shown, it is needless to say that other apparatus (for example, a DH) may be used.

Fig. 5 shows the result of investigating the relationship between the frequency of the reflux of molten steel after flux for desulfurization is added when molten steel having the components of Steel No. 2 in Table 1 is refined and the number of inclusions 20 microns or larger in size per square mm at a section of a steel sheet obtained by hot-rolling a slab cast from the molten steel. As shown in Fig. 5, by increasing the frequency of the reflux of molten steel, the surfacing of the desulfurization flux system inclusions is notably promoted, the number of coarse inclusions (20 microns or larger) can be reduced to not more than a prescribed number (not more than 0.3 per square mm), the net hole expansion rate is improved, and thus press cracking is avoided.

Next, the condition of the temperature at finish rolling in a hot-rolling process when a hot-rolled steel sheet according to the present invention is produced is examined. Fig. 6 shows the result of summarizing the relation among finish-rolling entry and exit temperatures when a slab having the components of Steel No. 2 in Table 1 is hot-rolled, and the maximum length of crystal grains in the microstructure at a section of the steel sheet obtained.

As shown in Fig. 6, by regulating the finish-rolling entry temperature at not lower than 960°C and the finish-rolling exit temperature at not lower than 780°C, the maximum length of the microstructure is certainly controlled to not larger than 10 microns and, therefore, a net hole expansion rate can be improved and press cracking can be avoided. Preferably, it is desirable to regulate the finish-rolling entry temperature in accordance with chemical components, finish-rolling speed

and finish-rolling exit temperature.

Here, if a finish-rolling exit temperature exceeds 920°C, the whole microstructure coarsens, the drawbacks such as the deterioration of press formability and the generation of scale defects remarkably appear, and therefore the temperature is determined to be the upper limit.

Though conditions on a cooling table after finish rolling are not particularly specified, the multi-step control of a cooling rate (the combination of quenching, slow cooling and isothermal retention) or immediate quenching at the finish-rolling exit, which are generally known, may be employed, aiming at the control of the area percentage of a microstructure and the promotion of the fining of a microstructure and the formation of a multi-phase structure.

The upper limit of a coiling temperature is set at 500°C in order for either one or both of retained austenite and martensite to account for 3% or more in total in area percentage. If a coiling temperature exceeds 500°C, the total area percentage of 3% or more cannot be secured and thus an excellent balance between strength and elongation (tensile strength multiplied by total elongation) is not obtained.

Here, either air cooling or forced cooling may be employed for the cooling of a steel sheet after it is coiled.

In addition, a slab may be subjected to rolling after once being cooled and then reheated, or rolling by HCR or HDR. Further, a slab may be produced by so-called thin slab continuous casting.

Furthermore, a steel sheet according to the present invention may be plated with Zn or the like for improving corrosion resistance, or may be coated with a lubricant or the like for further improving press formability.

Example

The chemical compositions other than Fe of the steels subjected to the test are shown in Table 2.

The production conditions in the steelmaking and hot rolling of the steels subjected to the test are shown in Table 3. The microstructures and material properties of hot-rolled steel sheets obtained are shown in Tables 4 and 5.

[Table 2]

Steel No.	Chemical components (mass %)												*1	*2	Remarks
	C	Si	Mn	P	S	Al	N	Ni	Cr	Cu	Mo	Others			
1	0.11	1.38	1.40	0.009	0.001	0.03	0.003	–	–	–	–		1.41	1.40	
2	0.10	1.40	1.40	0.008	0.001	0.04	0.002	–	–	–	–	Ca:0.0035	1.44	1.40	
3	0.09	1.35	1.36	0.010	0.001	0.04	0.002	–	–	–	–	B:0.001	1.39	1.36	
4	0.11	1.42	1.39	0.009	0.002	0.02	0.003	–	–	–	–	V:0.0011	1.44	1.39	
5	0.06	1.55	1.50	0.008	0.001	0.10	0.002	–	–	–	–	Ti:0.014	1.65	1.50	
6	0.06	1.51	1.53	0.006	0.001	0.03	0.002	–	–	–	–	Nb:0.012, REM:0.0015	1.54	1.63	
7	0.08	1.50	1.45	0.006	0.001	0.04	0.004	–	–	–	0.10		1.54	1.55	
8	0.08	1.49	1.54	0.015	0.002	0.03	0.004	–	–	0.15	–		1.52	1.69	P being outside range of present invention
9	0.14	1.39	1.26	0.009	0.001	0.03	0.003	–	0.16	–	–		1.42	1.42	
10	0.13	1.40	1.20	0.008	0.001	0.03	0.004	0.14	–	–	–		1.43	1.43	
11	0.06	1.25	1.29	0.008	0.001	0.03	0.003	–	–	–	–		1.28	1.39	
12	0.06	1.21	1.35	0.015	0.001	0.02	0.003	–	–	–	–		1.23	1.35	P being outside range of present invention
13	0.07	1.22	1.32	0.010	0.002	0.03	0.003	–	–	0.12	–		1.25	1.44	
14	0.09	1.10	1.30	0.009	0.001	0.03	0.004	–	0.08	–	–		1.13	1.38	
15	0.08	1.05	1.30	0.006	0.002	0.02	0.002	0.12	–	–	–		1.07	1.42	
16	0.11	1.98	1.95	0.009	0.001	0.03	0.003	–	–	–	–		2.01	1.95	
17	0.14	1.45	1.05	0.005	0.001	0.02	0.003	–	–	–	–		1.47	1.05	

*1 Al+Si (not including unavoidable impurities)

*2 Mn+Ni+Cr+Cu+Mo (not including unavoidable impurities)

[Table 3]

No.	Steel No.	Steelmaking conditions		Hot-rolling conditions		
		Frequency of circulation of molten steel, t (time) *1	Slab size, thickness x width (mm)	Finish-rolling entry temperature, FT0 (°C)	Finish-rolling exit temperature, FT7 (°C)	Size after finish rolling, thickness x width (mm)
1	1	1.7	250×950	960	855	3.2×850
2	1	3.5	250×950	1010	865	3.2×850
3	1	2.5	250×950	935	825	3.2×850
4	1	0.9	250×950	990	850	3.2×850
5	1	0.6	250×950	1040	895	3.2×850
6	2	1.5	250×1100	1035	875	3.2×850
7	3	1.6	250×1400	915	810	3.2×850
8	4	2.0	250×850	1020	860	3.2×850
9	5	1.7	245×1100	1025	865	2.9×920
10	6	1.6	245×1100	1000	855	2.9×920

[Table 3 - continued 1]

No.	Steel No.	Steelmaking conditions		Hot-rolling conditions		
		Frequency of circulation of molten steel, t (time) *1	Slab size, thickness × width (mm)	Finish-rolling entry temperature, FT0 (°C)	Finish-rolling exit temperature, FT7 (°C)	Size after finish rolling, thickness × width (mm)
11	7	0.7	250×1000	980	850	2.6×1000
12	8	2.4	250×1000	1020	870	2.6×1000
13	9	2.3	250×1000	945	835	3.0×990
14	10	1.7	250×950	985	856	3.0×990
15	11	2.6	250×950	990	860	9.2×1250
16	12	1.5	245×900	1010	890	3.2×1350
17	13	0.8	245×850	995	860	2.9×1215
18	14	1.8	235×1000	920	820	3.5×1350
19	15	1.2	235×950	1025	880	3.5×900
20	16	1.7	260×950	1000	855	9.2×850
21	17	1.7	260×950	960	855	9.2×850
22	17	1.7	250×950	960	930	3.2×850

[Table 3 - continued 2]

No.	Steel No.	Cooling conditions on cooling table	Coiling conditions Coiling temperature, CT (°C)	Remarks
1	1	50°C/sec.	415	
2	1	50°C/sec.	475	
3	1	50°C/sec.	400	FT0 being outside range of present invention
4	1	50–15–50°C/sec.	405	t being outside range of present invention
5	1	50°C/sec.	400	t being outside range of present invention
6	2	50°C/sec.	870	
7	3	50°C/sec.	410	FT0 being outside range of present invention
8	4	50°C/sec.	405	
9	5	55°/sec.	505	CT being outside range of present invention
10	6	55°C/sec.	440	

[Table 3 – continued 3]

No.	Steel No.	Cooling conditions on cooling table	Coiling conditions — Coiling temperature, CT (°C)	Remarks
11	7	60°C/sec.	415	t being outside range of present invention
12	8	60°C/sec.	360	FT0 being outside range of present invention
13	9	55°C/sec.	395	
14	10	55°C/sec.	410	
15	11	50°C/sec. after air cooling for 5 sec.	<100	
16	12	50-15-50°C/sec.	<100	t being outside range of present invention
17	13	50°C/sec. after air cooling for 5 sec.	<100	FT0 being outside range of present invention
18	14	50°C/sec. after air cooling for 5 sec.	<100	t being outside range of present invention
19	15	50°C/sec. after air cooling for 5 sec.	<100	
20	16	50°C/sec.	400	CT being outside range of present invention
21	17	50°C/sec.	600	
22	17	50-15-50°C/sec.	<100	FT7 being outside range of present invention

*1 The frequency of the reflux of molten steel can be calculated by, for example, the following equation.

The amount of refluxed molten steel Q expressed by the following equation is defined as the refluxed amount of one time:

Refluxed amount $Q = [11.4 \times V^{1/3} \times D^{4/3} \times \{ln(P1/P0)\}^{1/3}] \times 4$,

where

V: Flow rate of refluxed gas (Nl/min.), D: Sectional area of snorkel (m^2), P0: Pressure in vacuum chamber (Pa), and P1: Pressure at injection port of refluxed gas (Pa).

[Table 4]

No.	F Area percentage (%)	B Area percentage (%)	F+B Area percentage (%)	Retained γ Area percentage (%)	M Area percentage	Retained γ+M Area percentage (%)	Retained γ+M Average grain size (micron)	Remainder microstructure
1	84	11	95	5	0	5	2	
2	85	11	96	3	0	3	2	1%P
3	83	9	92	8	0	8	2	
4	85	10	95	5	0	5	2	
5	86	11	97	3	0	3	3	
6	84	10	94	6	0	6	2	
7	83	11	94	6	0	6	2	
8	85	11	96	4	0	4	2	
9	82	16	98	1	0	1	2	1%P
10	83	13	96	4	0	4	3	
11	82	13	95	5	0	5	2	

[Table 4 – continued 1]

No.	F Area percentage (%)	B Area percentage (%)	F+B Area percentage (%)	Retained γ Area percentage (%)	M Area percentage	Retained γ+M Area percentage (%)	Retained γ+M Average grain size (micron)	Remainder microstructure
12	60	13	93	3	4	7	2	
13	82	10	92	8	0	8	2	
14	82	11	93	7	0	7	2	
15	80	6	86	2	12	14	3	
16	80	4	84	3	13	16	3	
17	80	5	85	3	12	15	3	
18	82	6	88	0	12	12	3	
19	83	5	88	1	11	12	3	
20	65	30	95	5	0	5	2	
21	77	15	92	0	0	0	–	8%P
22	69	0	69	0	31	31	>10	

[Table 4 – continued 2]

No.	Maximum length of microstructure being 10 microns or smaller	Number of inclusions 20 microns or larger in size being 0.3 or less	Micro Vickers hardness of B being 240 or less	Remarks
1	○	○	○	
2	○	○	○	
3	×	○	×	Maximum length of microstructure being outside range of present invention
4	○	×	○	Number of inclusions being outside range of present invention
5	○	×	○	Number of inclusions being outside range of present invention
6	○	○	○	
7	×	○	×	Maximum length of microstructure being outside range of present invention
8	○	○	○	
9	○	○	○	γ+M being outside range of present invention
10	○	○	○	
11	○	×	○	Number of inclusions being outside range of present invention

[Table 4 - continued 3]

No.	Maximum length of microstructure being 10 microns or smaller	Number of inclusions 20 microns or larger in size being 0.3 or less	Micro Vickers hardness in of B being 240 or less	Remarks
12	O	O	×	
13	×	O	×	Maximum length of microstructure being outside range of present invention
14	O	O	O	
15	O	O	O	
16	O	O	×	
17	O	×	O	Number of inclusions being outside range of present invention
18	×	O	×	Maximum length of microstructure being outside range of present invention
19	O	×	O	Number of inclusions being outside range of present invention
20	O	O	O	
21	O	O	O	γ+M and P being outside range of present invention
22	×	O	–	γ+M and maximum length being outside range of present invention

Microstructure: F; ferrite, B; bainite, retained γ; retained austenite, M; martensite, and P; pearlite

[Table 5]

No.	Punching hole expandability		Static tensile properties					Remarks
	Net hole expansion rate λ (%)	TSxλ MPa·%	TS MpA	YS MpA	T.El %	YR %	TS×TEl MPa·%	
1	80	48320	604	476	36	0.79	21744	Invented example
2	94	56870	605	495	34	0.82	20570	Invented example
3	57	34884	612	494	34	0.81	20808	Comparative example
4	56	34832	622	465	35	0.75	21770	Comparative example
5	53	32595	615	491	32	0.80	19680	Comparative example
6	98	60760	620	496	33	0.80	20460	Invented example
7	56	34664	619	477	35	0.77	21665	Comparative example
8	85	51340	604	480	34	0.79	20536	Invented example
9	112	67312	601	485	28	0.81	16828	Comparative example
10	104	62400	600	466	35	0.78	21000	Invented example
11	55	33385	607	471	34	0.78	20638	Comparative example
12	50	30950	619	490	32	0.79	19808	Comparative example
13	55	34375	625	468	35	0.75	21875	Comparative example
14	105	64890	618	472	34	0.76	21012	Invented example
15	75	46575	621	410	33	0.66	20493	Invented example
16	45	27810	618	399	32	0.65	19776	Comparative example
17	40	25160	629	411	31	0.65	19499	Comparative example
18	46	29440	640	421	29	0.66	18560	Comparative example
19	45	28530	634	409	31	0.65	19654	Comparative example
20	81	63261	781	560	29	0.72	22649	Invented example
21	70	42350	605	540	26	0.89	15780	Comparative example
22	30	23400	780	535	23	0.69	17940	Comparative example

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Here, the evaluations of properties and
microstructures were carried out by the following
methods.

Tensile test was carried out with JIS No. 5 test
5   pieces, and tensile strength (TS), yield strength (YS),
yield ratio (YR = YS/TS x 100), total elongation (T.EL),
and the balance between strength and elongation (TS x
T.EL) were obtained.

A net hole expansion rate was calculated based on
10   the Japan Iron and Steel Federation Standard JFS T1001-
1996.

The maximum length of crystal grains in a
microstructure was calculated from an optical micrograph
under the magnification of 400 taken at a section
15   perpendicular to the rolling direction of a steel sheet
after the section was etched with a nitral reagent and
the reagent disclosed in Japanese Unexamined Patent
Publication No. S59-219473.

The number of coarse inclusions in a steel sheet was
20   obtained by observing a polish-finished section
perpendicular to the rolling direction of a steel sheet
with a microscope (400 magnifications) and integrating
the number of coarse inclusions 20 microns or larger in
maximum length.

25   The identification of the constitution of a
microstructure, the measurement of an area percentage,
and the measurement of the maximum length of retained
austenite and/or martensite were carried out with an
optical micrograph under a magnification of 1,000 x taken
30   at a section perpendicular to the rolling direction of a
steel sheet after the section was etched with a nitral
reagent, the reagent disclosed in Japanese Unexamined
Patent Publication No. S59-219473 and the reagent
disclosed in Japanese Unexamined Patent Publication No.
35   H5-163590, and with X-ray analysis.

An area percentage of retained austenite (Fγ: in %)
was calculated according to the following equation based

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on Mo-Kα rays in X-ray analysis:

Fγ (%) = (2/3) {100/(0.7 x α(211) / γ(220)+1)} +

(1/3) {100/(0.78 x α(211) / γ(311)+1)},

where, α(211), γ(220), α(211), and γ(311) represent the
intensity on the respective planes.

In the examples of the present invention (Nos. 1, 2,
6, 8, 10, 14, 15 and 20), as shown in Table 5, high
strength hot-rolled steel sheets excellent in press
formability, having both an excellent balance between
strength and hole expandability (not less than 35,000
MPa% in terms of the value obtained by multiplying a
tensile strength by a net hole expansion rate) and an
excellent balance between strength and elongation (not
less than 18,500 MPa% in terms of the value obtained by
multiplying a tensile strength by a total elongation),
are obtained.

On the other hand, in the comparative examples (Nos.
3 to 5, 7, 9, 11 to 13 and 16 to 19), since some
conditions are outside the range of the present invention
as explained at the remarks in Tables 1 to 3, steel
sheets having poor mechanical properties (poor properties
in a balance between strength and hole expandability and
a balance between strength and elongation) are obtained
by all means.

The present invention has made it possible to
provide, stably and at a low cost, a multi-phase steel
sheet excellent in press formability, having both an
excellent balance between strength and hole expandability
and an excellent balance between strength and elongation,
and a method of producing the steel sheet, and,
consequently, the ranges of the application and the
service conditions have markedly been expanded and the
industrial and economical effects of the present
invention are remarkable.

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CLAIMS

1.   A multi-phase steel sheet excellent in hole expandability characterized in that:
                    the steel sheet contains, as chemical components in mass,
        C: 0.03 to 0.15%,
        P: not more than 0.010%,
        S: not more than 0.003%, and
either one or both of Si and Al in a total amount of 0.5 to 4%, and one or more of Mn, Ni, Cr, Mo and Cu in a total amount of 0.5 to 4%, with the balance consisting of Fe and unavoidable impurities;
                    the microstructure at a section of the steel sheet is composed of either one or both of retained austenite and martensite which account(s) for 3 to 30% in total in area percentage and the balance consisting of either one or both of ferrite and bainite;
                    the maximum length of the crystal grains in the microstructure is not more than 10 microns; and
                    the number of inclusions 20 microns or larger in size at a section of the steel sheet is not more than 0.3 piece per square millimeter.

2.   A multi-phase steel sheet excellent in hole expandability characterized in that:
                    the steel sheet contains, as chemical components in mass,
        C: 0.03 to 0.15%,
        P: not more than 0.010%,
        S: not more than 0.003%, and
either one or both of Si and Al in a total amount of 0.5 to 4%, and one or more of Mn, Ni, Cr, Mo and Cu in a total amount of 0.5 to 4%, with the balance consisting of Fe and unavoidable impurities;
                    the microstructure at a section of the steel sheet is composed of either one or both of retained austenite and martensite which account(s) for 3 to 30% in total in area percentage, pearlite which accounts for

more than 0% to not more than 3% in area percentage, and
the balance consisting of either one or both of ferrite
and bainite;

the maximum length of the crystal grains
5   in the microstructure is not more than 10 microns; and

the number of inclusions 20 microns or
larger in size at a section of the steel sheet is not
more than 0.3 piece per square millimeter.

3.   A multi-phase steel sheet excellent in hole
10   expandability according to claim 1 or 2, characterized in
that the micro Vickers hardness of bainite is less than
240.

4.   A multi-phase steel sheet excellent in hole
expandability according to any one of claims 1 to 3,
15   characterized by further containing, as chemical
components in mass, one or more of Nb, V and Ti in a
total amount of 0.3% or less.

5.   A multi-phase steel sheet excellent in hole
expandability according to any one of claims 1 to 4,
20   characterized by further containing, as a chemical
component in mass, B of 0.01% or less.

6.   A multi-phase steel sheet excellent in hole
expandability according to any one of claims 1 to 5,
characterized by further containing, as chemical
25   components in mass, either one or both of Ca of 0.01% or
less and REM of 0.05% or less.

7.   A method of producing a multi-phase steel sheet
excellent in hole expandability, which steel sheet
contains, as chemical components in mass,
30   C: 0.03 to 0.15%,
P: not more than 0.010%,
S: not more than 0.003%, and
either one or both of Si and Al in a total amount of 0.5
to 4%, and one or more of Mn, Ni, Cr, Mo and Cu in a
35   total amount of 0.5 to 4%, with the balance consisting of
Fe and unavoidable impurities, characterized by:

when molten steel with said components is

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refined, circulating the molten steel not less than 1.5 times after flux for desulfurization is added at the time of the desulfurization of the molten steel;

5   further, when a steel sheet is produced by hot-rolling a slab obtained by casting said molten steel, conducting the finish rolling by controlling the finish-rolling entry temperature to 950°C or higher and the finish-rolling exit temperature within the range from 780 to 920°C; and

10   coiling the steel sheet thus obtained at a temperature of 500°C or lower.

8.   A method of producing a multi-phase steel sheet excellent in hole expandability according to claim 7, characterized in that the steel sheet further contains,

15   as chemical components in mass, one or more of Nb, V and Ti in a total amount of 0.3% or less.

9.   A method of producing a multi-phase steel sheet excellent in hole expandability according to claim 7 or 8, characterized in that the steel sheet further

20   contains, as a chemical component in mass, B of 0.01% or less.

10.   A method of producing a multi-phase steel sheet excellent in hole expandability according to any one of claims 7 to 9, characterized in that the steel sheet

25   further contains, as chemical components in mass, either one or both of Ca of 0.01% or less and REM of 0.05% or less.
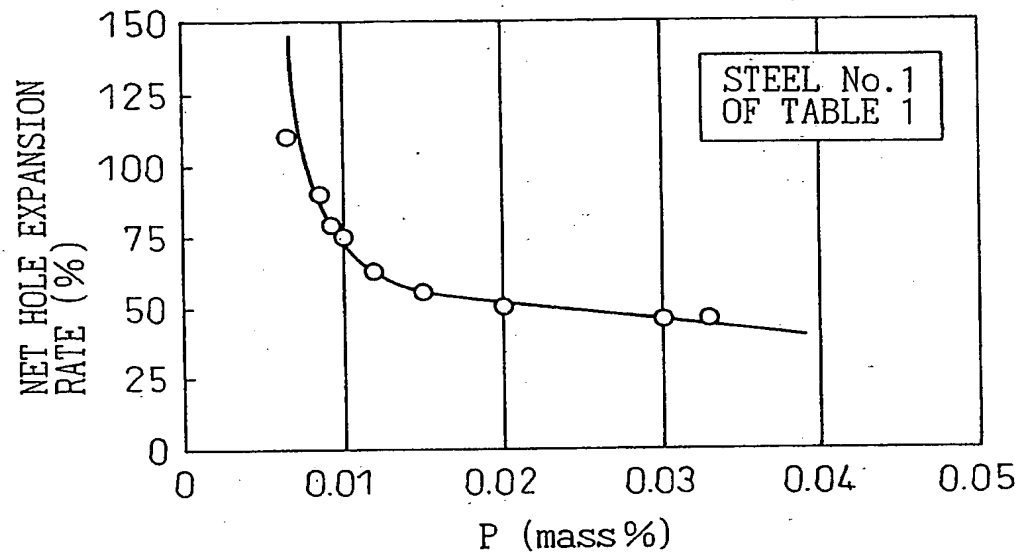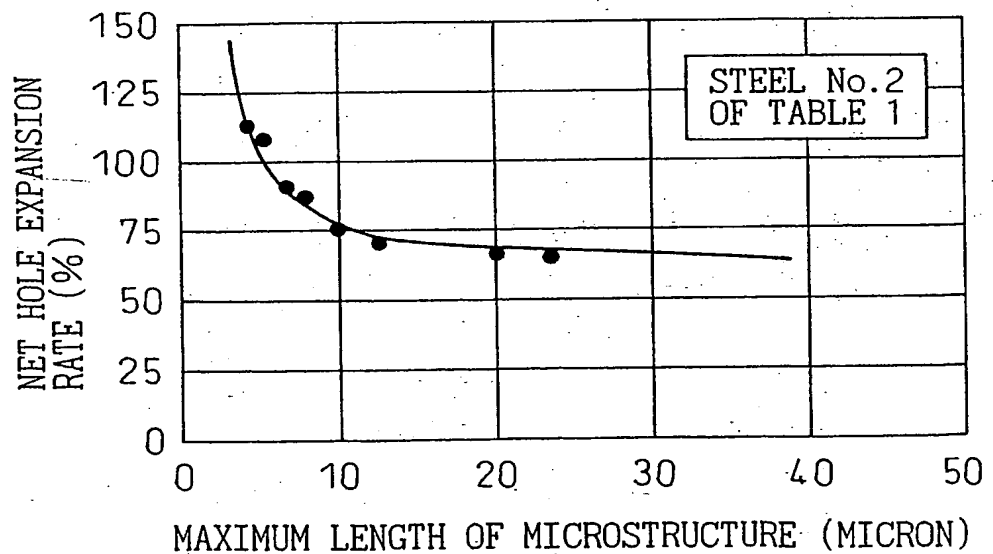
Fig.1

Fig.2

Fig.3

STEEL No.2
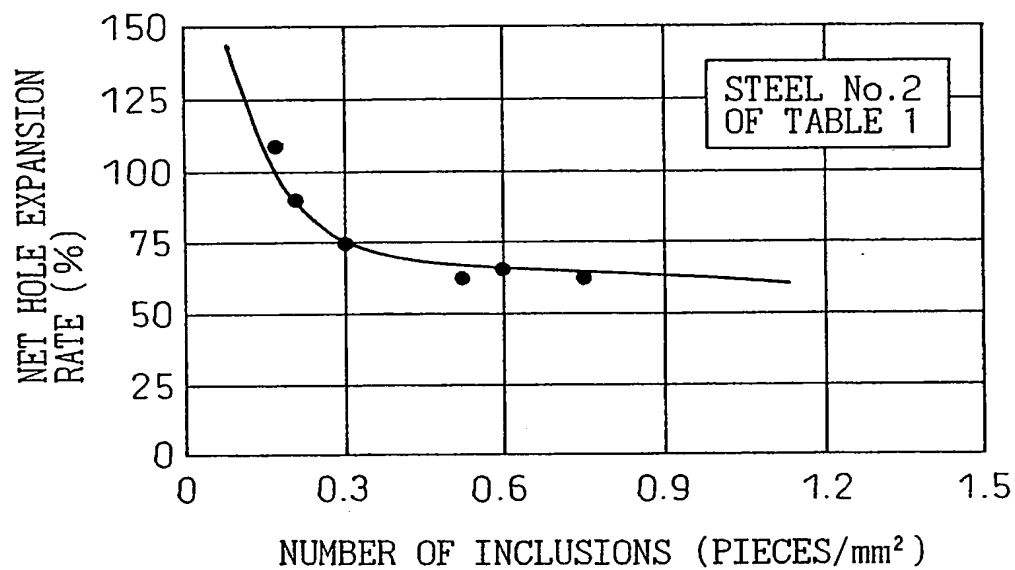OF TABLE 1

NET HOLE EXPANSION RATE (%)

150
125
100
75
50
25
0

0   0.3   0.6   0.9   1.2   1.5

NUMBER OF INCLUSIONS (PIECES/mm²)

Fig.4

Ar

2 DEGASSING CHAMBER

4 INJECTION LANCE

3 SNORKEL

1 MOLTEN STEEL LADLE

Fig.5

BASED ON
STEEL No.1
OF TABLE 1

NUMBER OF INCLUSIONS (PIECES/mm²)

FREQUENCY OF CIRCULATION OF MOLTEN
STEEL AFTER THE ADDITION OF
DESULFURIZING FLUX (TIMES)

Fig.6

● MAXIMUM LENGTH OF MICROSTRUCTURE
  BEING 10 MICRONS OR SMALLER
○ MAXIMUM LENGTH OF MICROSTRUCTURE
  BEING LARGER THAN 10 MICRONS

BASED ON
STEEL No.2
OF TABLE 1

SCOPE OF
THE INVENTION

FINISH-ROLLING EXIT
TEMPERATURE (℃)

FINISH-ROLLING ENTRY TEMPERATURE (℃)
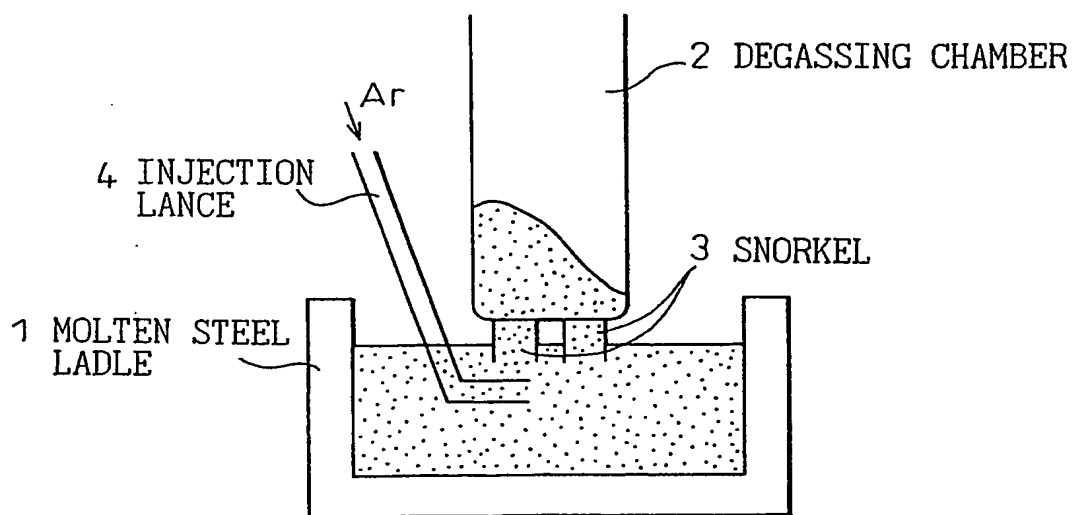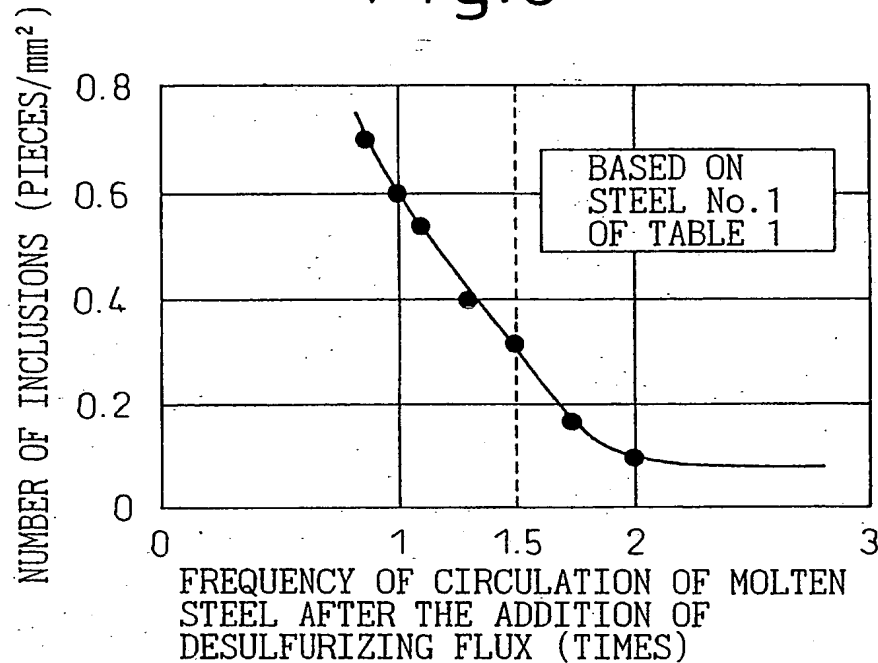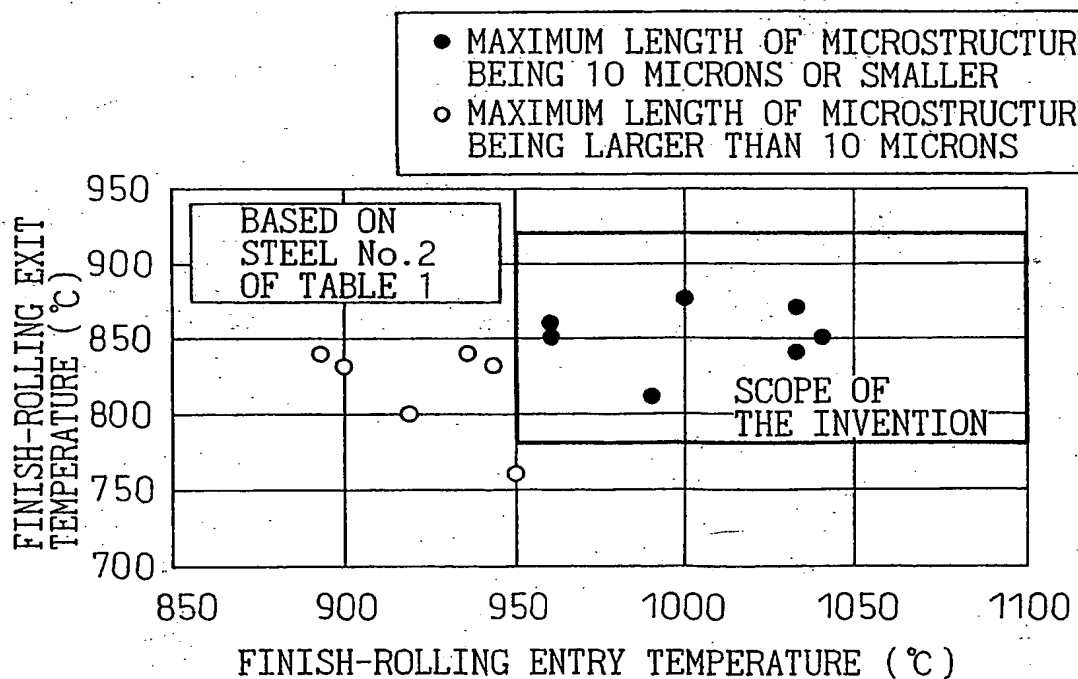
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   C22C38/00   C22C38/02   C22C38/04   C22C38/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   C22C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 997 548 A (KOBE STEEL LTD) 3 May 2000 (2000-05-03)	1,4-6
A	the whole document claims 1-6; examples B,2; tables 1-3	2,7-10
X	PATENT ABSTRACTS OF JAPAN vol. 1996, no. 02, 29 February 1996 (1996-02-29) & JP 07 252592 A (NIPPON STEEL CORP), 3 October 1995 (1995-10-03) abstract; tables 1-3	1,6
A	US 5 470 529 A (KUNISHIGE KAZUTOSHI ET AL) 28 November 1995 (1995-11-28) tables 1-11	1

-/--

[X]	Further documents are listed in the continuation of box C.	[X]	Patent family members are listed in annex.

° Special categories of cited documents :

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 December 2002	16/12/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax (+31–70) 340–3016	Lilimpakis, E

Form PCT/ISA/210 (second sheet) (July 1992)

BNSDOCID: <WO   03010351A1_I_>

INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
P,A	EP 1 201 780 A (NIPPON STEEL CORP) 2 May 2002 (2002-05-02) claims 1-14; tables 1-4	1
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 06, 22 September 2000 (2000-09-22) & JP 2000 087144 A (NKK CORP), 28 March 2000 (2000-03-28) abstract; tables 1,2	1
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 01, 31 January 2000 (2000-01-31) & JP 11 279694 A (NIPPON STEEL CORP), 12 October 1999 (1999-10-12) abstract; tables 1,2	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 0997548	A	03-05-2000	EP	0997548 A1	03-05-2000
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